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# Engineering Reliability Analysis – Component Degradation Functions & Event Trees to Forecast the Structural Performance of Major Lock Components

10 May 2006, Langdon

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# Engineering Reliability Analysis

**Reliability is a measure of a facility or component to perform its intended function under specified operating conditions for a given period of time.**

$$P(f) + P(s) = 1$$

*where: P(f) is the probability of failure (# failures / # simulations) and P(s) is the probability of survival (# sucessess / # simulations)*

**Probability of satisfactory performance is :**

$$1 - p(f) = R = \text{Reliability}$$

**Documented as Degradation Functions and Event Trees**

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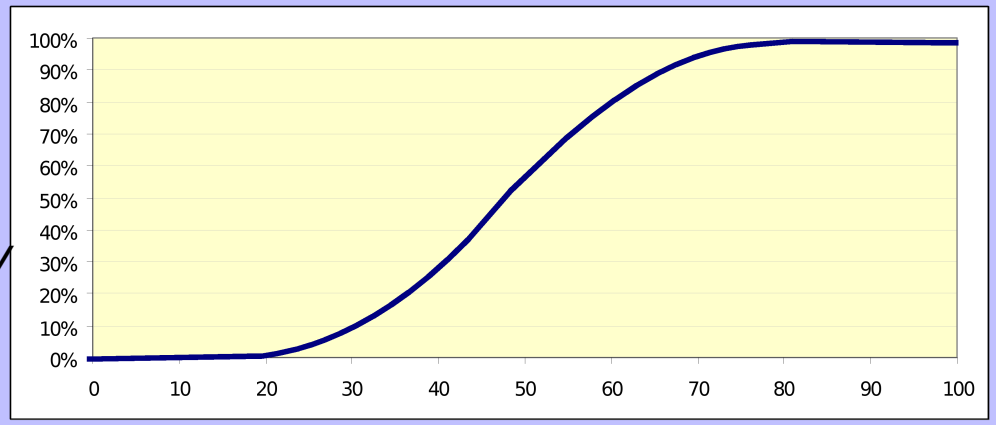
# Component Degradation Functions (a.k.a. Hazard Function or PUP)

**The hazard function, h(t), is the <u>conditional</u> probability of unsatisfactory performance of a facility or component in a specified time period, given that it has survived up to the selected time period.**

$$h(t) = f(t)/R(t)$$

*f(t) = the performance density function*

*R(t) = the reliability function*



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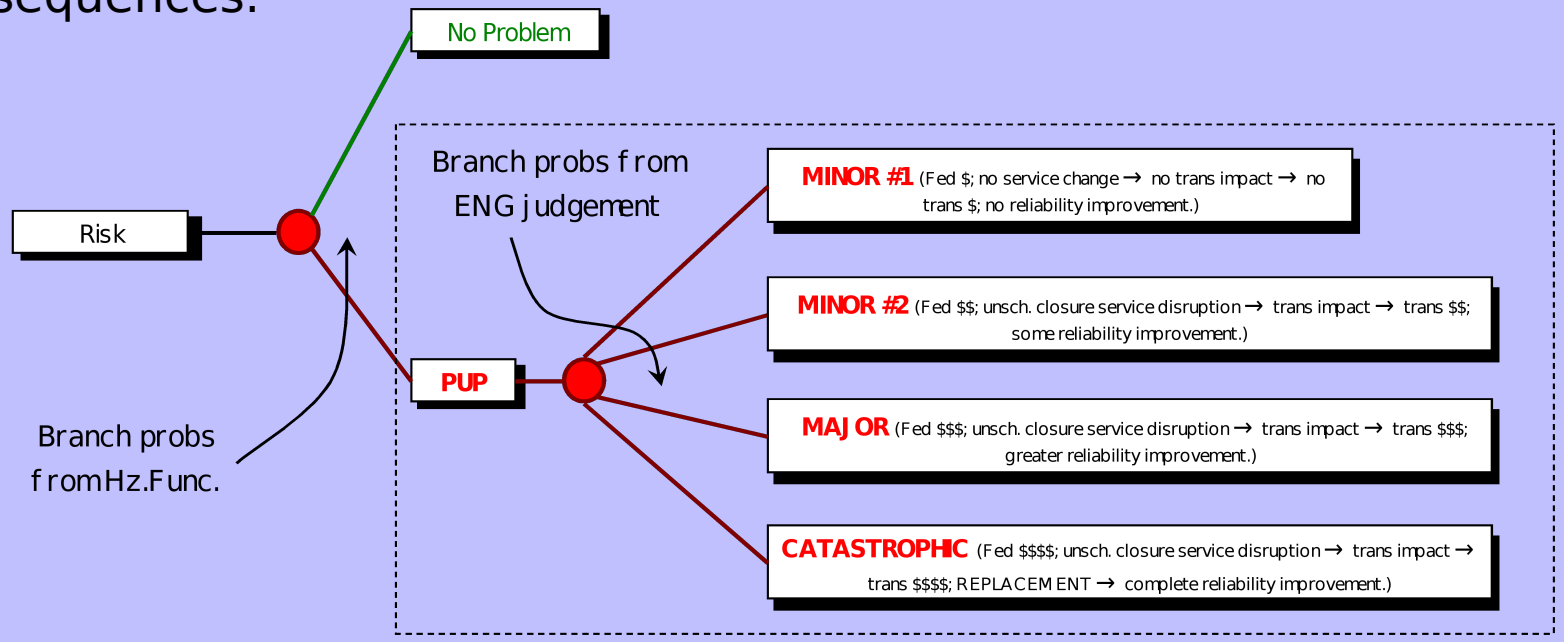
# Event Trees → map risk consequences

**Risk =** potential to experience a loss. May be expressed as the product of the probability of an adverse event and its consequences.

**Failure (PUP) consequences:**

- Repair expense
- Repair duration
- Future reliability
- Future maintenance cycles (freq. & durations)


No Problem
Risk
Branch probs from ENG judgement
PUP
Branch probs from Hz.Func.
MINOR #1 (Fed $; no service change → no trans impact → no trans $; no reliability improvement.)
MINOR #2 (Fed $$; unsch. closure service disruption → trans impact → trans $$; some reliability improvement.)
MAJOR (Fed $$$; unsch. closure service disruption → trans impact → trans $$$; greater reliability improvement.)
CATASTROPHIC (Fed $$$$; unsch. closure service disruption → trans impact → trans $$$$; REPLACEMENT → complete reliability improvement.)

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# Why are we concerned?

Service disruptions can cause significant transportation impacts which need to be considered.

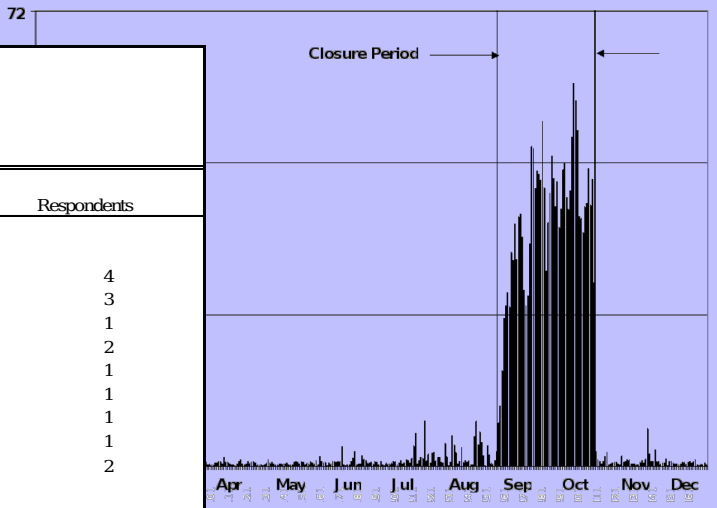
TABLE 7

Greenup Closure Costs to Industry

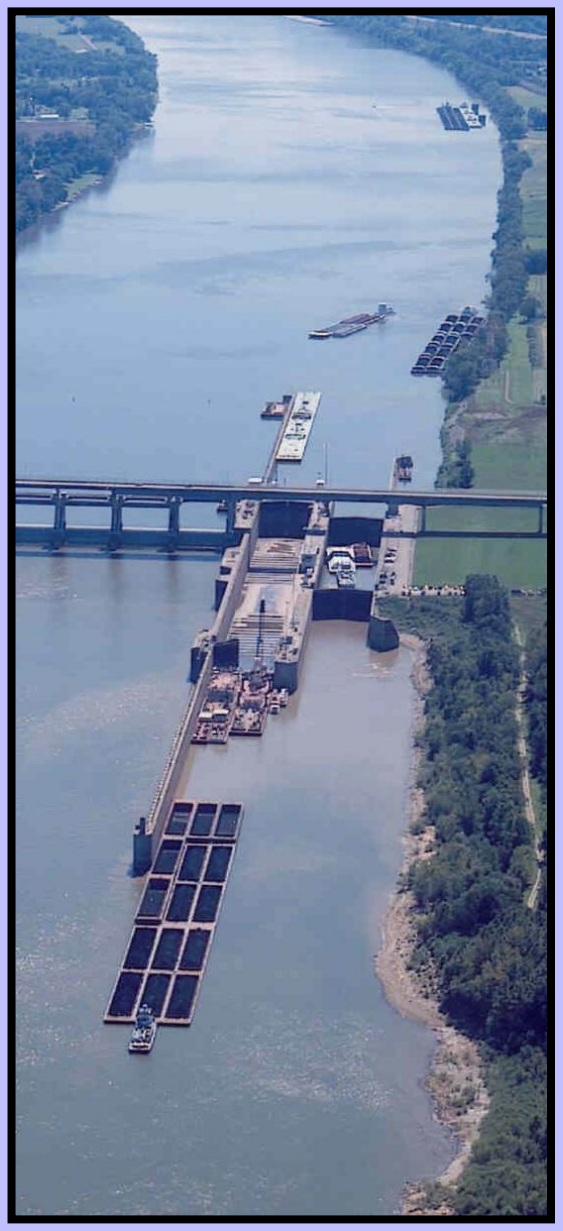
| Type of Cost | Cost (Thousand $) | Respondents |
|---|---|---|
| Costs from Surveys: | | |
| Modal Shift | 8,600 | 4 |
| Sourcing Shift | 1,900 | 3 |
| Stockpiling | 25 | 1 |
| Altered Production Processes | 220 | 2 |
| Shift in Production Location | 36 | 1 |
| Demurrage | 10 | 1 |
| Additional Equipment | 2,500 | 1 |
| Lost Sales | 13,100 | 1 |
| Other Costs | 2,300 | 2 |
| Computed Costs: | | |
| Delay at Lock | 13,200 | - |
| Total | 41,891 | 16 |

**FIGURE 7**

**AVERAGE DAILY TOW DELAYS AT GREENUP IN 2003**




**Source: IWR NETS Event Study, Shipper & Carrier Response to the September – October 2003 Greenup Main Lock Closure, February 2005. U.S. Army Corps of Engineers, PCXIN**



**Greenup 2003**

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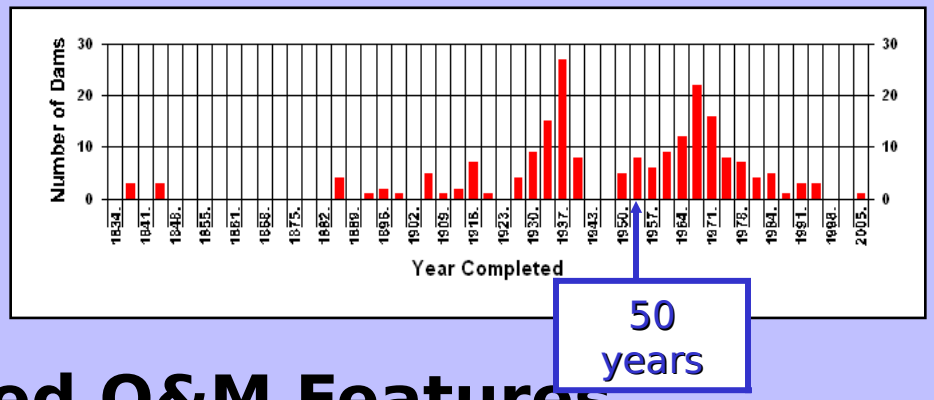
# Sigificant to our analysis?




- **Aging Infrastructure**
  - 46% over 50-years
- **Backlog of Non-Funded O&M Features**
  - 1998 O&M critical items est. $200 million.
  - 2004 O&M critical items est. $1.01 billion ($623M in nav.projects).
- **Increasing unscheduled outages**
  - System-wide chamber closure time has doubled since 1990.
- **Continued tight budget**
  - FYDP, RBRCR, etc.

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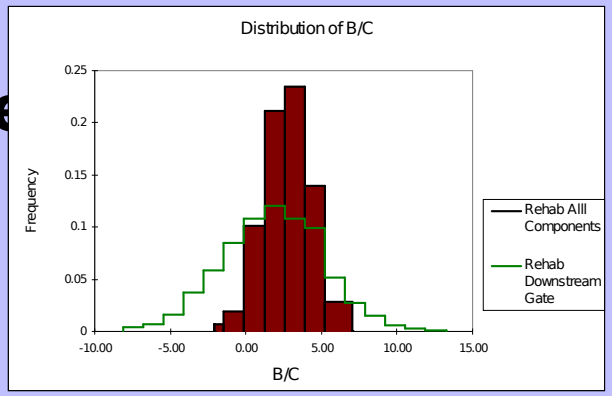
# Propagating Risk in our Cost-Benefit Analysis

**GOAL:** integrate engineering reliability information (risk & uncertainty) with economic consequences into our cost-benefit analysis to help make better decisions. Point estimates become expected values with associated distributions.

- **Analytical Solution**
  - full enumeration may not be feasible.
- **Monte Carlo simulation proce**
  - generates a sample of realizations.



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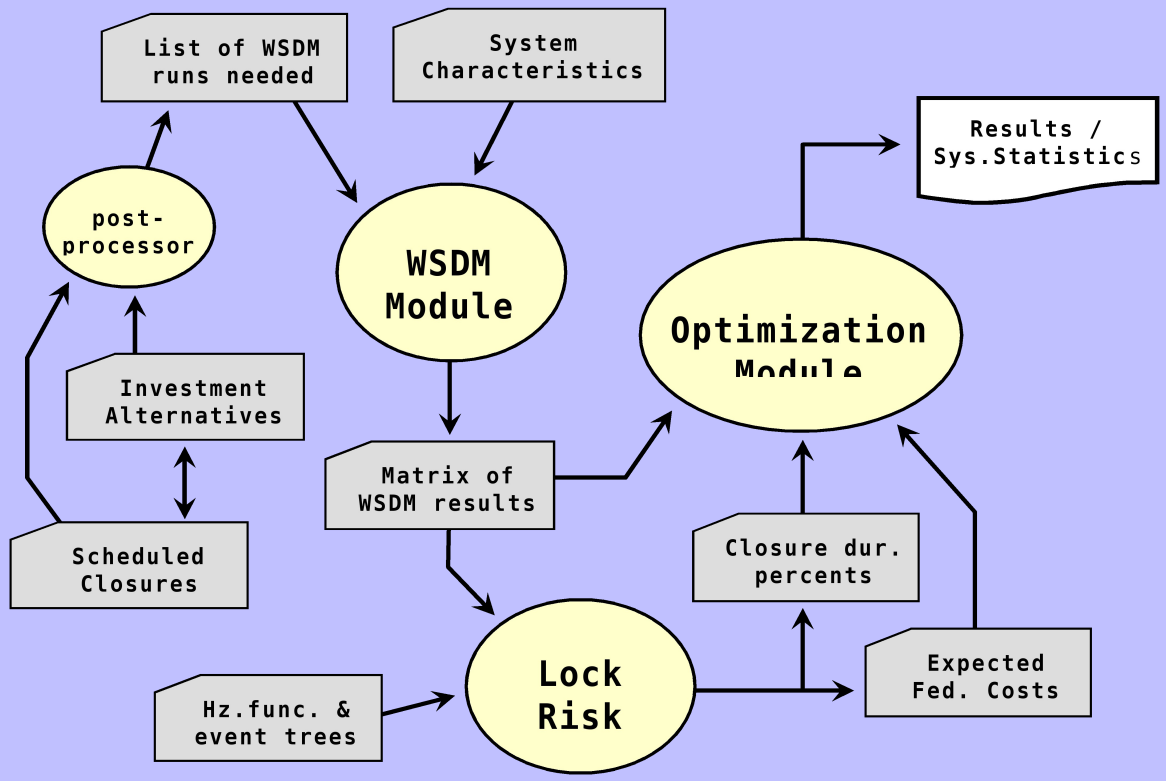
# Ohio River Navigation Investment Model

ORNIM was developed by the Oak Ridge National Laboratory, Center for Transportation Analysis for the Great Lakes and Ohio River Division. ORNIM consists of a suite of analysis tools used to:

- cost annual waterway movements given infrastructure reliability;
- determine the equilibrium traffic level on the waterway system; and
- to optimize system infrastructure investments to maximize net benefits to the country.



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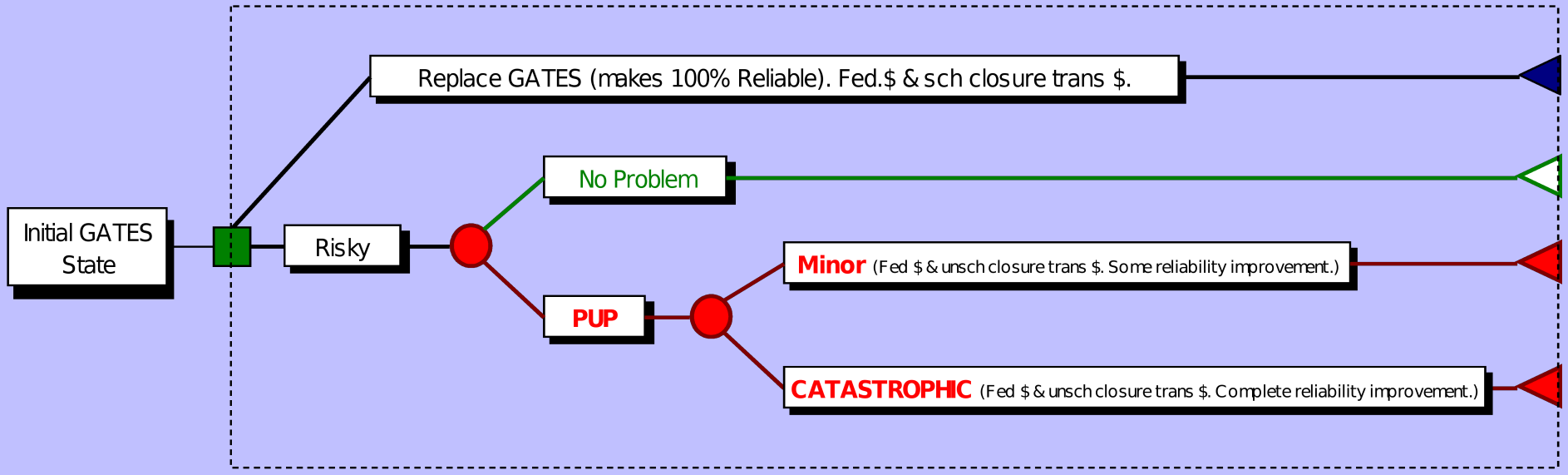
# ORMSS Example

ORMSS has 168 components at 35 lock chambers analyzed over 61-years and 5 forecast scenarios.

Question 1: Should a component be scheduled for replacement and if so, what is the optimal replacement year?

**Real Simple Tree (1-period):**


Initial GATES State
Risky
Replace GATES (makes 100% Reliable). Fed.$ & sch closure trans $.
No Problem
PUP
Minor (Fed $ & unsch closure trans $. Some reliability improvement.)
CATASTROPHIC (Fed $ & unsch closure trans $. Complete reliability improvement.)

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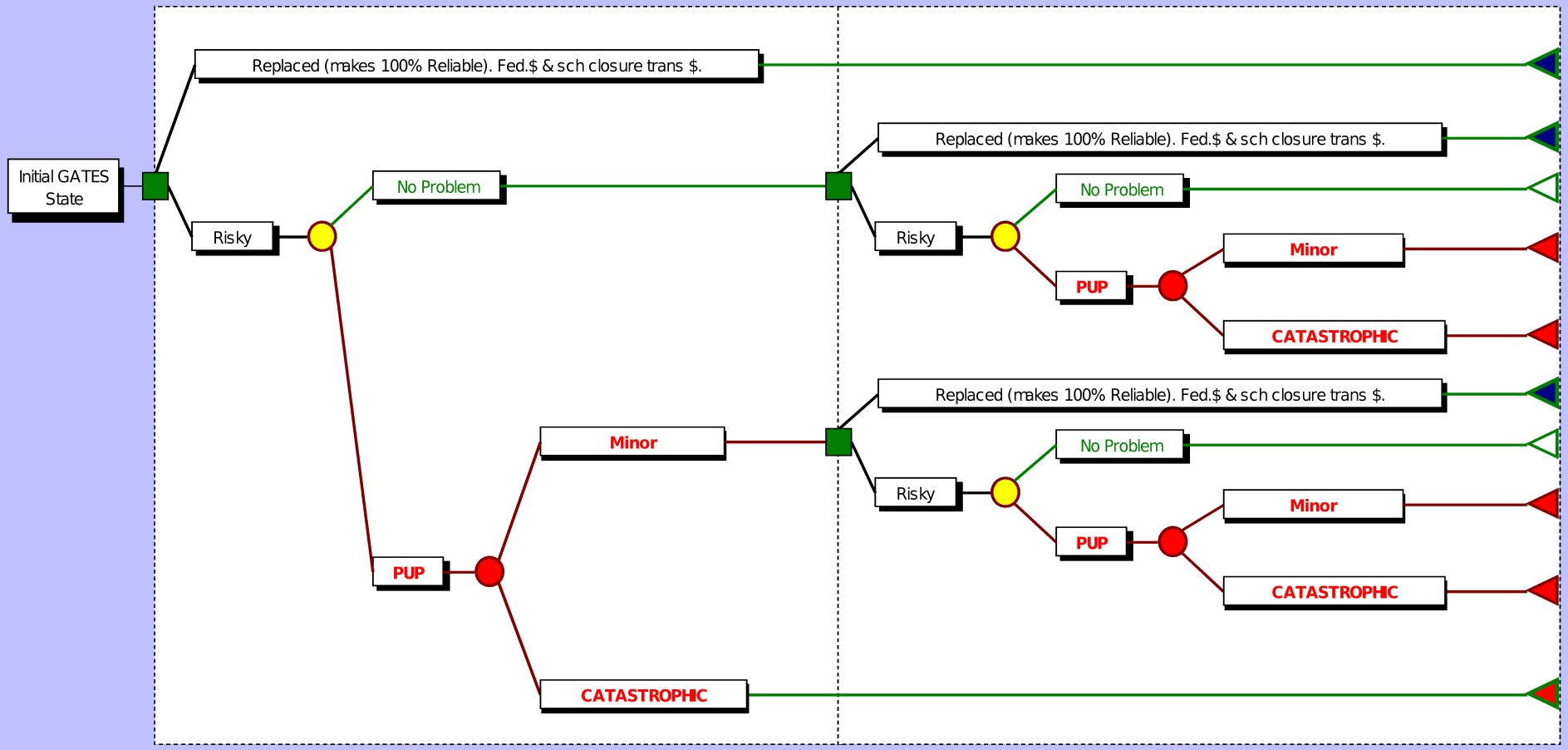
## Real Simple Tree (2-periods):



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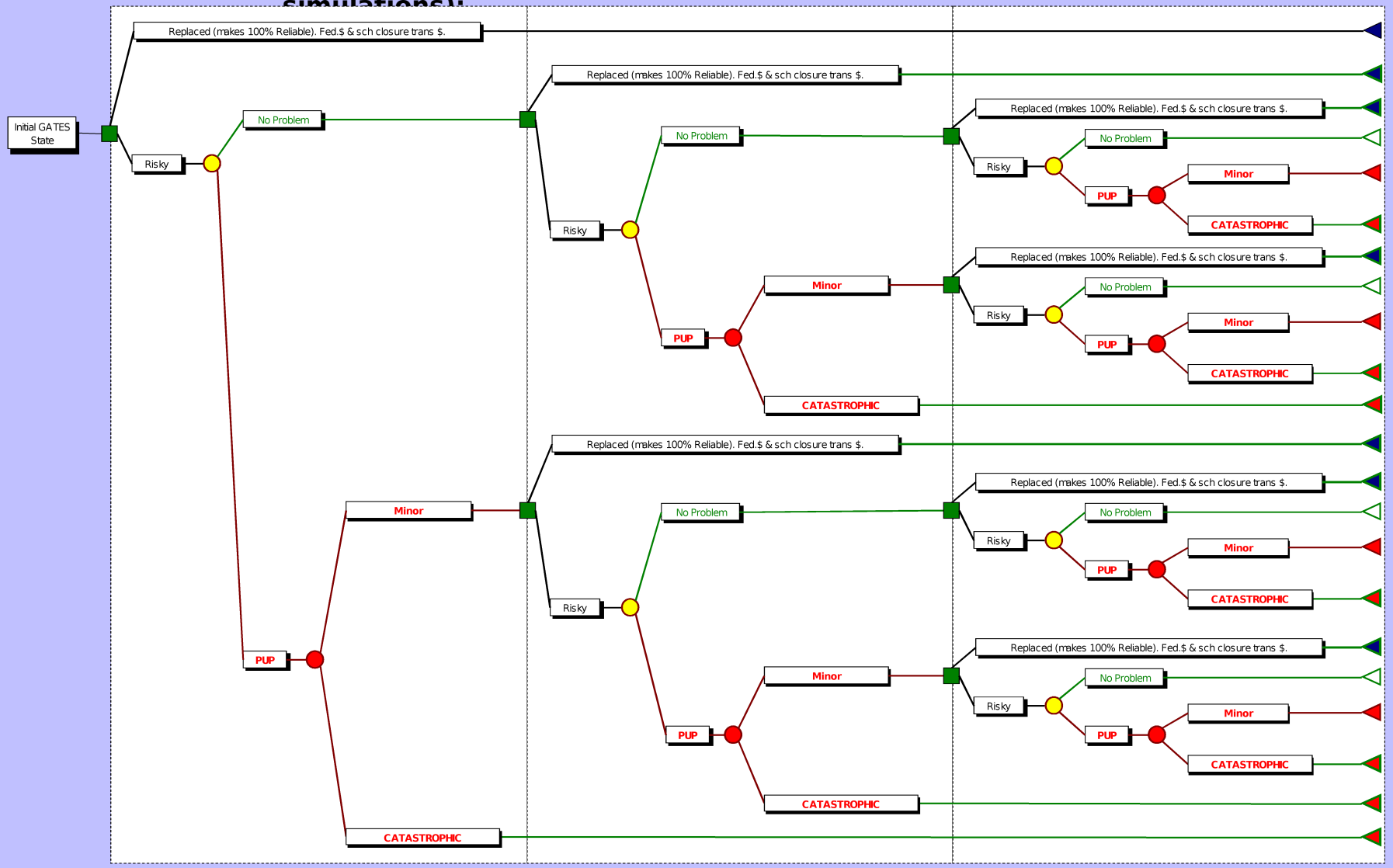
## Real Simple 3-period Tree (ORMSS is 61-period, 250,000 simulations):



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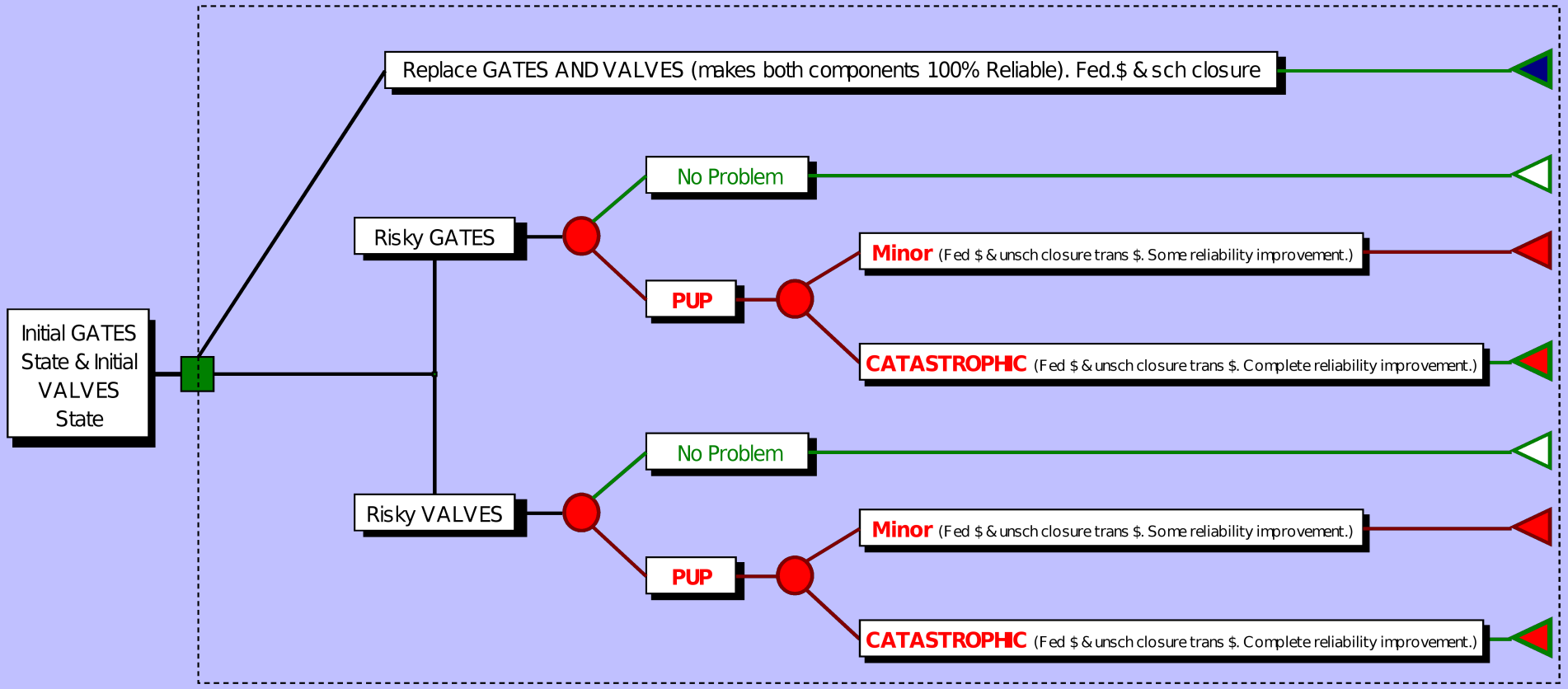
# ORMSS Example

Question 2: Should multiple components at a project be bundled together in a scheduled replacement (a.k.a. rehabilitation) and if so, what is the optimal replacement year?

**Real Simple Bundled Tree (1-period):**


Initial GATES State & Initial VALVES State
Replace GATES AND VALVES (makes both components 100% Reliable). Fed.$ & sch closure
Risky GATES
No Problem
PUP
Minor (Fed $ & unsch closure trans $. Some reliability improvement.)
CATASTROPHIC (Fed $ & unsch closure trans $. Complete reliability improvement.)
Risky VALVES
No Problem
PUP
Minor (Fed $ & unsch closure trans $. Some reliability improvement.)
CATASTROPHIC (Fed $ & unsch closure trans $. Complete reliability improvement.)

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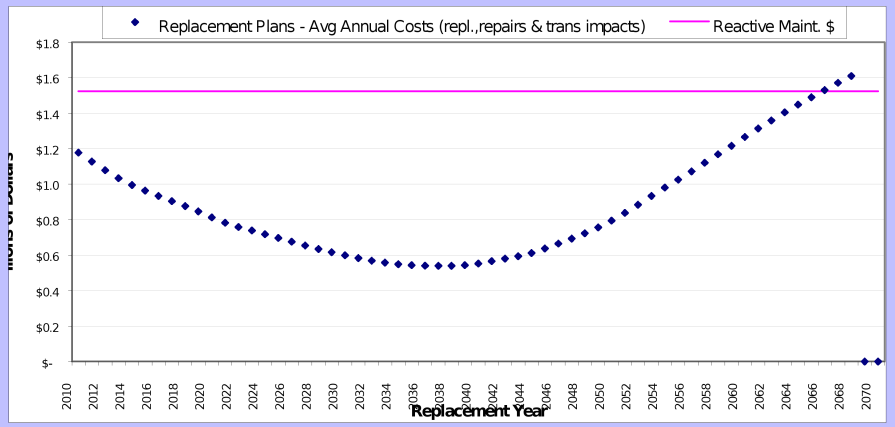
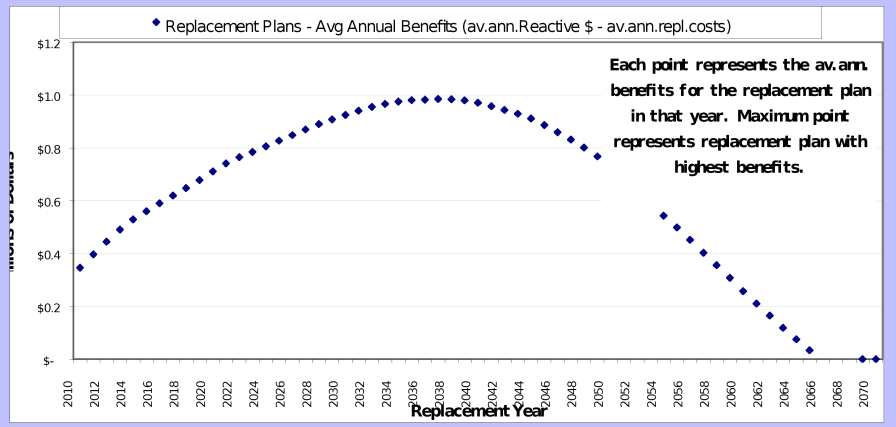
# ORNIM Output

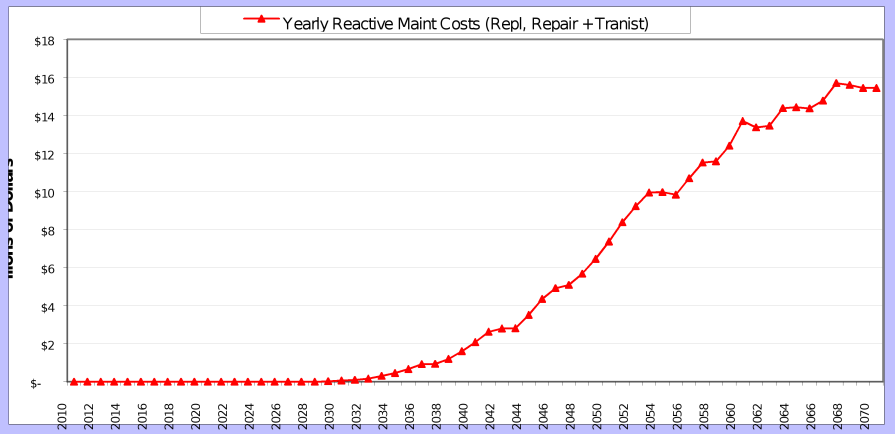
## NEWBURGH Main - Gate (NAAOS Growth)

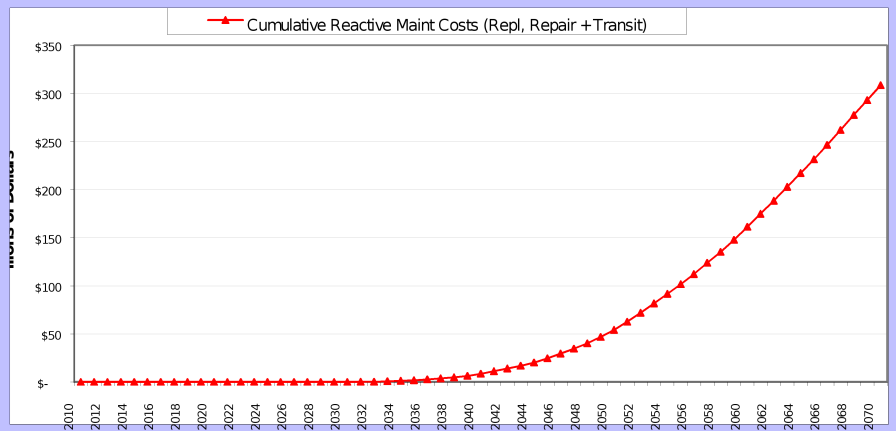
| | |
|---|---|
| 2010 | <-- Beginning Year of Analysis |
| 2010 | <-- Base Year of Analysis |
| 5.125% | <-- Federal Discount Rate |
| eoy | <-- Discount Method (boy, moy, eoy) |
| 61 | <-- Number of periods (years) |

**The component was selected by ORNIM Optimization Module in year 2037**





Replacement Plans - Avg Annual Benefits (av.ann.Reactive $ - av.ann.repl.costs)
Each point represents the av.ann. benefits for the replacement plan in that year. Maximum point represents replacement plan with highest benefits.
Millions of Dollars
Replacement Year



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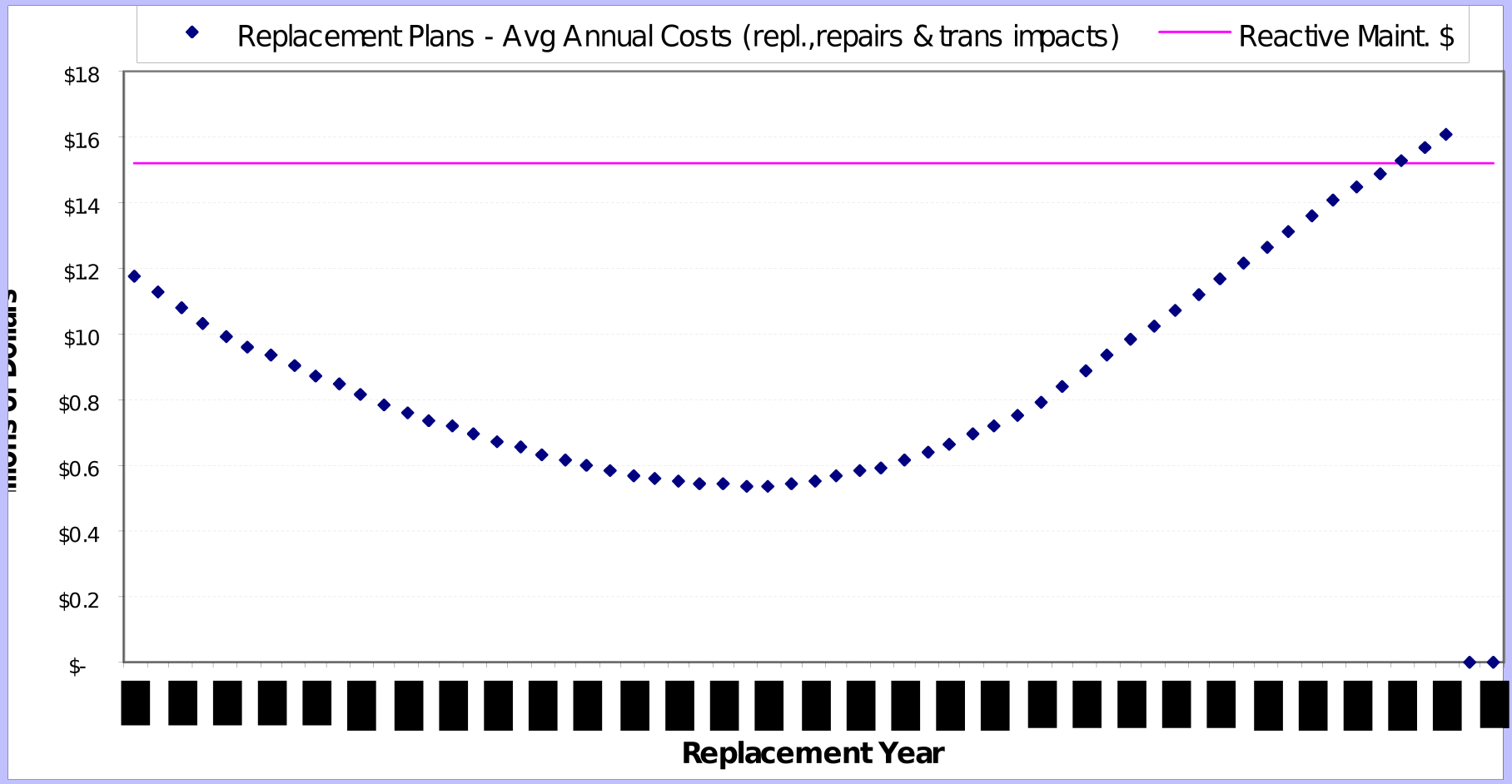
# ORNIM Output



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# Some References


**Tools for Risk Based Economic Analysis. February 1999. IWR Report 99-R-2. U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA.**

**Beyond Expected Value: Making Decisions Under Risk and Uncertainty, September 2002. Richard M. Males, RRM Technical Services.**

**Guidelines for Risk and Uncertainty Analysis in Water Resources Planning, Volume I Principals. March 1992. IWR Report 92-R-1. U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA.**

**Guidelines for Risk and Uncertainty Analysis in Water Resources Planning, Volume II Examples. March 1992. IWR Report 92-R-1. U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA.**

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# QUESTIONS ?